A Practical Study For a New Measuring Tool For EHV Bus Bar Fault Detection

Ali M. El-Rifaie, Rania M. Sharkawy, Sherif Haggag

***Abstract*— This paper introduces both theoretical and practical application of the Cos-Sin fault detection technique with EHV busbars. A digital relay with multiple operating criteria is being implemented based on the Cos-Sin technique. The relay is being theoretically tested on the 500 KV unified Egyptian network where the grid simulation is done using ATP whereas the technique was programmed by the Matlab. On the other hand, the relay is being practically tested against different fault cases on a constructed lab model of a simple network with typical parameters to the actual grid while the protection mechanism was loaded on the LabVIEW. The simulation results indicate the capability of the Cos-Sin based relay for the detection and discrimination of all types of busbar faults besides differentiating between close up faults and bus ones.**

***Index Terms*— Busbar Protection, Extra High Voltage Networks, Digital relays, travelling waves, Cos-Sin.**

I. INTRODUCTION

Busbar in power system is that critical compact element linking between generation, transmission and load circuits. Both failure to trip and false tripping operations of bus bar protective devices are not allowed since they may result in either severe damage or a remarkable service loss. Gradual evolution of the supplied load requires continuous and flexible operating service therefore station arrangement designs were grown to become more sophisticated and consequently the traditional way of busbar protection became insufficient. Microprocessors based relays were developed in the last century quarter where they have similar in principle to their electro mechanical counterparts. Although there are very few algorithms for protecting busbars have been published, most of them attempt to overcome the problems of current transformers' saturation in differential protection as it is being considered the most popular way in busbar protection.

Y.C. Kang discussed the design, evaluation and implementation of a busbar differential protection relay that operates in conjunction with a current transformer compensating algorithm [1]. The compensating algorithm detects the start of first saturation on the basis of the third-difference function of the current and estimates the core flux at the first saturation start by inserting the negative value of the third-difference function of the current into the magnetisation curve of a CT. Thereafter, it calculates the core flux and then the corresponding magnetising current in conjunction with the magnetisation curve. The calculated magnetizing current is added to the measured secondary current to obtain the correct secondary current

O. Bagleybter and S. ubramanian describe a Transient Bias technique designed to overcome the effects of Current Transformer saturation [2]. This Transient Biasing is only active during transient conditions in the power system, and it decays quickly once the transients disappear .

Crossely and Kang [3] introduced a busbar current differential protection relay that operates in conjunction with a current transformer saturation detection algorithm. The detection algorithm detects the start and end of each saturation period based on the third-difference function of the current. A blocking signal is activated during saturation and for one cycle after it ends.

A. Ramírez introduced a new algorithm [4] for the differential protection of a power transformer based on the Principal Component Analysis. The algorithm involves the pattern recognition from differential current data. Its purpose is to discriminate between energization and over-excitation conditions and transformer short-circuits introduced.

M.E.Eissa describes an approach that distinguishes faults in a busbar protection zone from these outside the zone. The technique is based on the concept of continuous wavelet transform CWT based basis function where the Morlet wavelet is used as the basis function [5]. Also he proposed another technique that utilizes wavelet packet transform to extract features from fault current signal [6].

In this paper, a fault detection tool that uses the square value of the instantaneous voltage signal and its complement to produce a unity relation in normal conditions is highlighted and a simulation study is done on an EHV busbar, with the 500 kV unified Egyptian network parameters [7]. The suggested Cos-Sin tool [8-11] is being applied on both the bus voltage signal and the extracted line travelling waves, where fault detection criteria are formed to detect busbar fault presence besides differentiating between line and bus faults.

The technique was tested practically on a laboratory transmission line model during normal conditions and in case of busbar and line fault conditions. .

II. COS-SIN TOOL

The Cos-Sin algorithm was introduced several years ago and succeeded in detecting the fault occurrence in some electric network elements such as transmission lines and busbars. It is one of the rare methods that depend basically on voltage signal transient analysis to capture the fault presence.

In this tool both the instantaneous voltage samples Va(t) measured from the system and its generated complementary signal Vg(t) are squared, added and normalized to produce a discrimination signal M(t) that can be expressed as:

$$M(t) = \cos^2(wt + \varnothing) + \sin^2(wt + \varnothing)$$

M(t) is a unity relation as long as there is no effective change in the value of the peak voltage and no extraordinary condition taking place yet, this unity relation is distorted as soon as a fault

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occurs. The Cos-Sin tool can be applied effectively over any sinusoidal signal in the power system.

Due to errors in sampling process and non-exact uniform sinusoidal source, M(t) is not a pure unity relation, some ripples oscillating around unity appears in this calculated signal. Therefore upper and lower threshold limits are initiated to separate between normal and fault cases and since the maximum permissible variation in the voltage signal of the high voltage network is ±5%, a voltage detection thresholds "ζ" of a value ±0.05 is used.

III. RELAY CRITERIA

A. *Fault Pick up*

The purpose of this criterion is to detect the exact fault instance and to trigger the subsequent criteria if needed. In this criterion Cos-Sin technique is applied to the system voltage signal measured from busbar needed to be protected, discrimination signal M(t) is calculated for all phases then a comparison is made to check whether the output value is within the threshold limits "ζ" or not.

B. *Fault Analysis*

The average deviation "δ" in M(t) over one complete cycle time starting from the instant of fault occurrence is computed to increase dependability and to avoid any false tripping that might happened during switching or sudden load change which usually cause a short time disturbances in the system signals. In addition, average discrimination for currents flow in all lines attached to the protected busbar δMi(t) are taken and analyzed to obtain the faulted phase.

C. *Fault Discrimination*

A supplementary criterion has been developed to increase the protection reliability parameter and to provide a discrimination technique that differentiates between faults located on the busbars and others happened somewhere else. The additional criteria utilizes the extracted electromagnetic travelling waves that appears with fault incidence and propagates along all transmission grid connected to that busbar with almost light speed. Criterion rely on applying the Cos-Sin to the positive aerial mode (mode 2) derived from the modal analysis to obtain arrival time of both forward and backward travelling wave by the relay installed on the bar (T_f and T_b). The time shift detected between forward and backward waves indicates the faulted element and accordingly prevent false tripping.

IV. SOFTWARE SIMULATION STUDY

In EHV networks the peak voltage (V_{max}) doesn't affect much with fluctuation of the grid major dynamics loads which makes it a suitable field to apply the busbar protection technique mentioned above. Figure 1 represents a section of an actual 500 KV network.

This section consists of four busbars and three transmission lines connecting them, the network was simulated using the Alternative Transient Program (ATP) at a sampling frequency of 10 KHz, whereas the proposed algorithm was programmed by the Matlab software. Voltage transformers is connected to the targeted busbar to fed the tool obtainer directly with the system instantaneous voltage while current transformers were used to obtain the amperage flow through lines in between in order to monitor travelling waves needed in the previously mentioned third criterion.

Figures 2 (a, b, c, d) show results of LG fault located on the busbar (F1) where [a] represent the discrimination signal M(t) while [b, c, d] is the discriminated travelling waves MT(t) in the three transmission lines respectively. Figures 3 (a, b, c, d) show results of LG fault located on the busbar (F2) where [a] represent the discrimination signal M(t) while [b, c, d] is the discriminated travelling waves MT(t) in the three transmission lines respectively. Table 1 shows the deviation in unity relation δM(t) during all fault types in all three phases during a busbar fault.

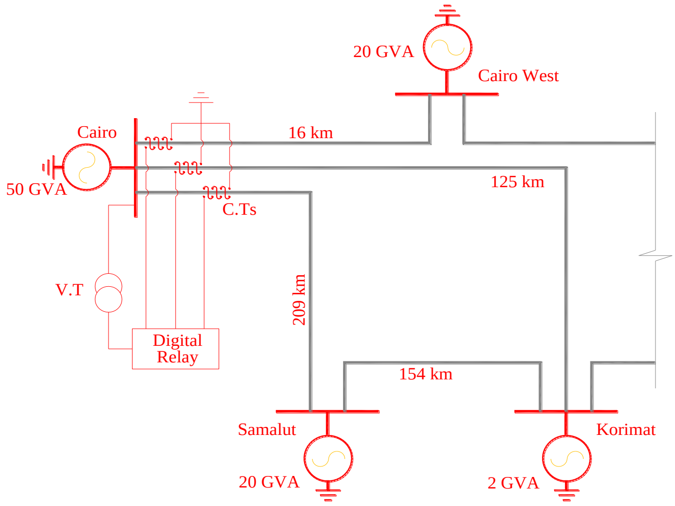
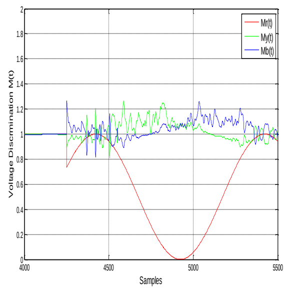
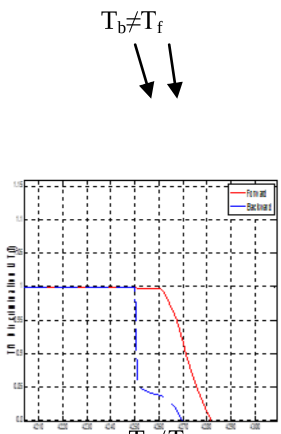


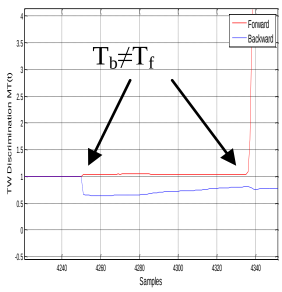
Figure 1. 500 kV, typical network used in simulation



(a)

(b)





(c)

(d)

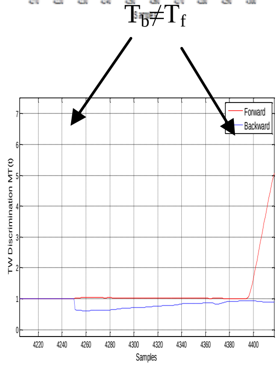


Figure 2 (a, b, c, d). BB LG fault M(t), MT(t)

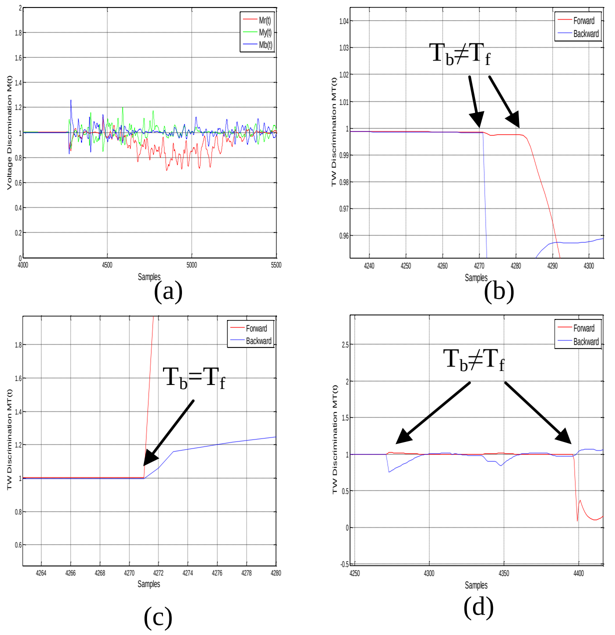


Figure 3 (a, b, c, d). Line 2, LG fault M(t), MT(t)

TABLE 1. Deviation in unity relation during different fault types.

Cairo busbar fault type	δM(t) over one complete cycle		
	δM-A	δM-B	δM-C
L-G	*0.4786*	0.0217	0.0175
L-L	*0.374*	0.001	0.371
L-L-G	*0.504*	0.076	0.503
L-L-L	*0.508*	0.507	0.511

From table 1, it is clear that we can conclude the faulted phases by analyzing discrimination values δM(t) in all three phases. Faulted phases average discrimination always exceed the threshold limits determined by 0.05; however these analysis are not enough to distinguish busbar faults from line ones, especially those occurring close to the busbar as they have almost the same influences.

As seen in figures 2, 3 (b, c, d) the discrimination between bus faults and line faults can be achieved by analyzing forward and backward discriminated travelling waves $MT_F(t)$ and $MT_B(t)$ where the instant of their deviation from unity (T_f & T_b) holds the information about the faulted element. When MT_F (t) and MT_B (t) deviate in different times ($T_f \neq T_b$) in all connected lines then the fault located in the bar itself while if they deviate in the same moment ($T_f = T_b$) in a certain line then this line is the defected one.

V. Experimental Impelemnentation

The experiment aims to investigate practically the capability of the above mentioned protection technique to detect the fault instant accurately besides confirming the fault location in the network. 400 V lab model is simulating an actual 500 KV network, EHV transmission line model is used. The model consists of identical PI-sections, where each section represents a transmission line of 25 Km long, 400 V three phase balanced source is used as a supply and a three phase induction motor with a shaft brakes is representing a dynamic load. The line mutual coupling for both inductance and capacitance are considered. The protection technique was programmed using LabVIEW [12] and system signals were delivered to the data acquisition card (DAQ) via voltage and current transformers.

Figure 4 presents the connection of the laboratory equipment where the fault can be obtained through a single phase variable resistor. Figures 5(a,b) show the travelling wave behavior during bar fault (F_1) and line fault (F_2). Figure 6(a) represents both the instantaneous voltage besides its generated complementary signal in normal case while figure 6(b) represents the correspondent currents of the motor. The discrimination signal obtained is illustrated in figure 6(c).

Figure 4. lab. network model

Fault was applied to feeding node to represent a busbar fault. Phase voltage and generated signal are shown in red and black in Figure 7(a) respectively whereas the corresponding discrimination signal is introduced in Figure 7(b).

In Figure 8(a) the fault was applied on the transmission line and the computed discrimination signal is shown in Figure 8(b).

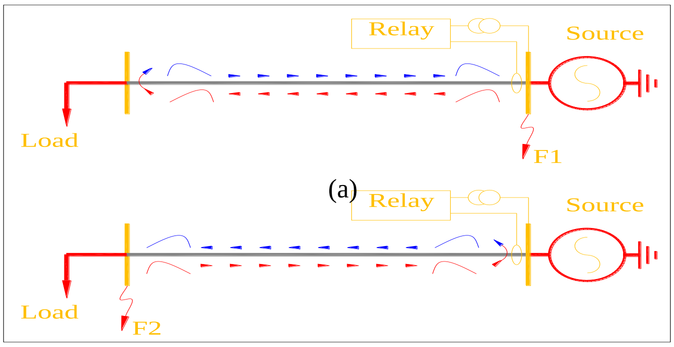
Figures 9(a, b and c) represent discriminated travelling waves in normal conditions, line fault and busbar fault respectively. Time of deviation of the forward and backward signal T_f and T_b was identical in the line fault but during bar fault slight different appears between T_f and T_b.

It clearly appears that only for bus faults, a difference between T_f and T_b always takes place, while for line faults, T_f and T_b are always equal for the faulted line.

VI. Conclusion

This paper highlights a suggested tool for detecting the faults in EHV busbars. Matlab simulation that applied to a section of the 500KV network in Egypt managed to detect the fault and to discriminate busbar faults from line ones by extracting the travelling wave and apply simple mathematical calculation on it. Practical application of the suggested Cos-Sin tool on a laboratory model with actual parameters was performed; LabVIEW was used for interfacing where the model practically represents a part of the Egyptian Unified 500 kV network.

A large degree of conformance appeared in both simulation and practical results. Where bus bar fault detection and discrimination took place within 20 msec (F= 50 Hz). The Cos-Sin tool is characterized by being simple, fast, accurate and easily implementable within a digital relaying scheme.



(b)

Figure 5 (a,b). Travelling wave Theory.

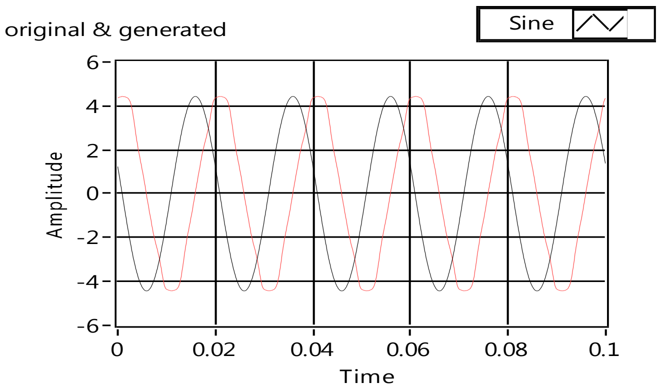


Figure 6(a). Input phase voltage and complementary generated signal during normal conditions.

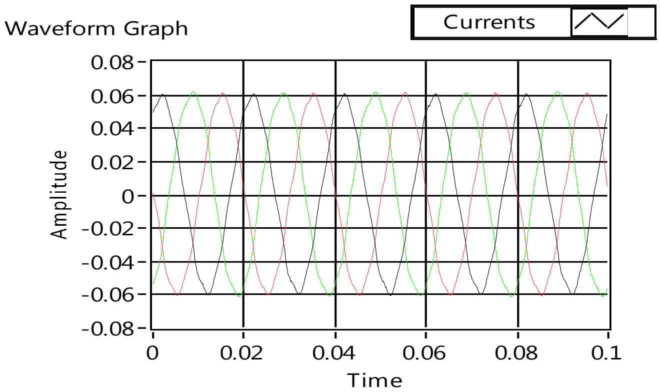


Figure 6(b), System 3 phase current signal during normal conditions.

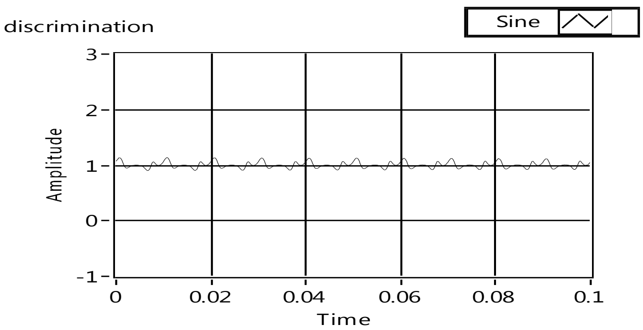


Figure 6(c), resultant discrimination signal during normal conditions.

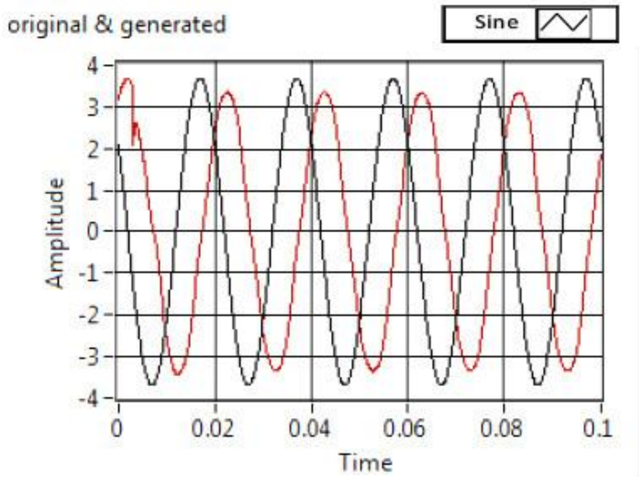


Figure 7(a). Input phase voltage and complementary generated signal during BB fault conditions.

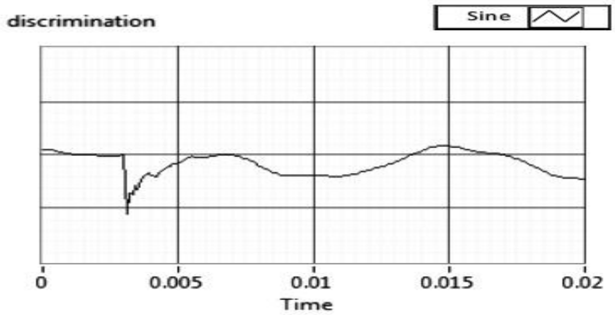


Figure 7(b), resultant discrimination signal during BB fault conditions.

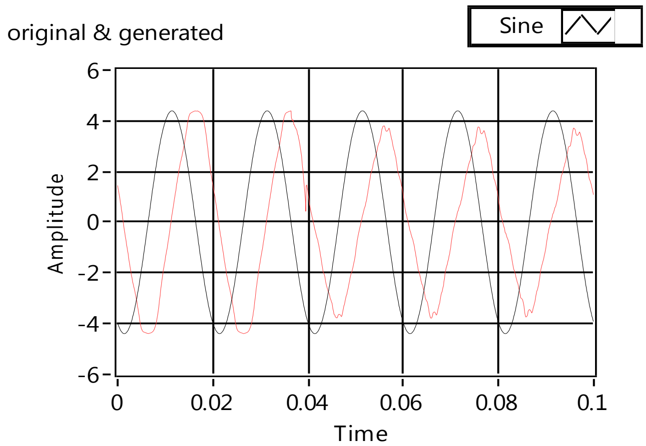


Figure 8(a). Input phase voltage and complementary generated signal during line fault conditions.

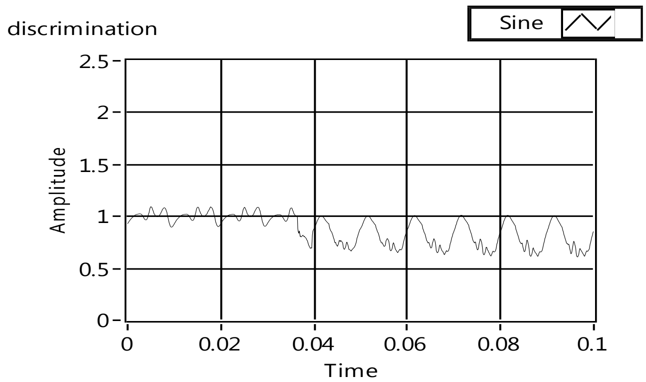


Figure 8(b), resultant discrimination signal during line fault conditions.

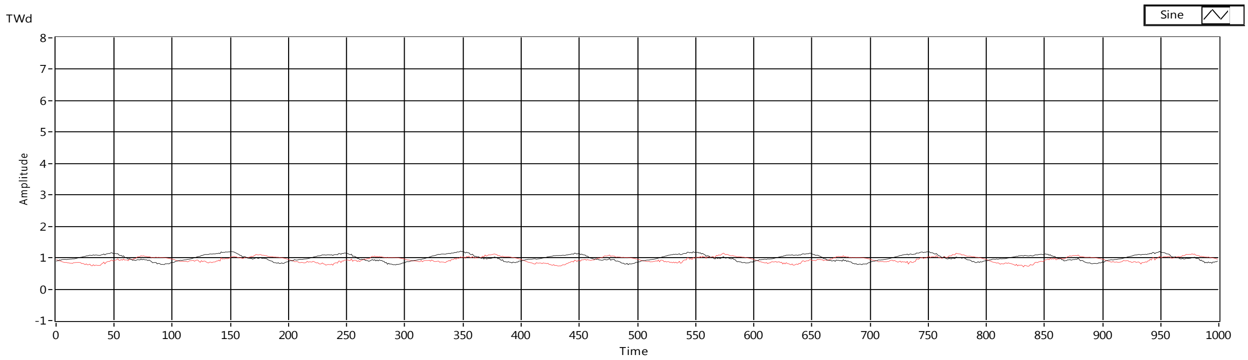


Figure 9(a), Forward and backward discriminated traveling waves in no fault condition.

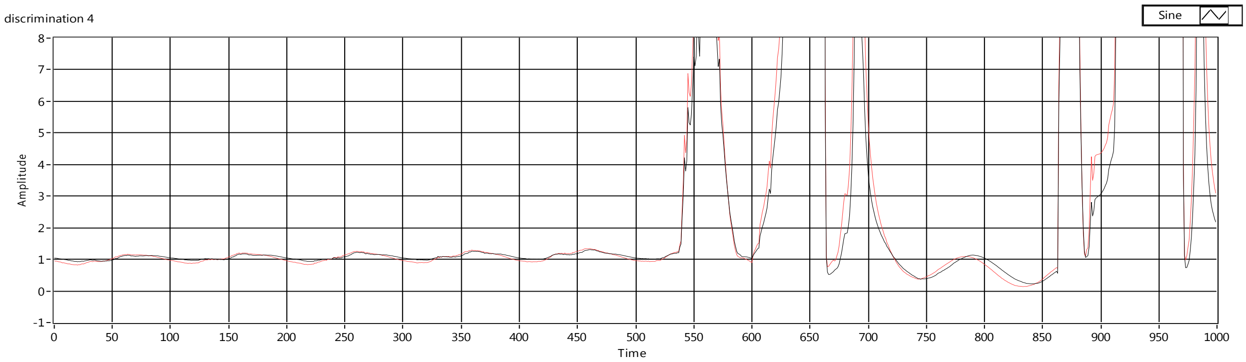


Figure 9(b), Forward and backward discriminated traveling waves in line fault condition.

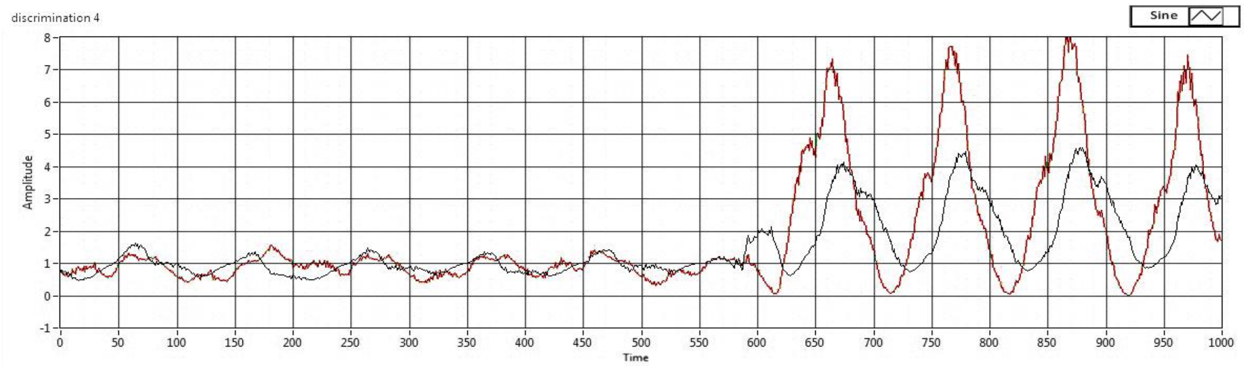
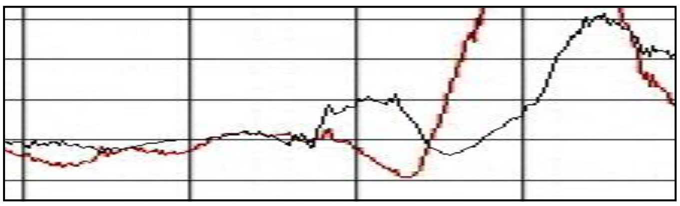


Figure 9(c), Forward and backward discriminated traveling waves in BB fault condition.



Snap shot on the T_b and Tf deviation in figure 9(c).

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